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First record of *Amphoromorpha/Basidiobolus* fungus on centipedes (Geophilomorpha, Geophilidae) from Brazilian caves

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Abstract

We identified *Basidiobolus* fungi on geophilomorphan centipedes (Chilopoda) from caves of Southeast Brazil. Twelve specimens of centipedes of the family Geophilidae were examined, and two of them carried the secondary capilliconidia of *Basidiobolus* on their exoskeleton. The fungus uses the surface of the exoskeleton as a support for the asexual reproductive structure. In this manner, the host is used for the purpose of dispersing its spores. This study expands current knowledge of the diversity of arthropods used as host for the fungus, and in particular for *Basidiobolus*, living in cave habitats.

Keywords

Cave habitat, fungus-host relationship, Chilopoda, capilliconidia, Brazil

Introduction

Fungi are abundant cave microorganisms owing to their high dispersion rate, spore survival, and colonization capacity (Wang et al. 2010, Paula et al. 2016). In 1914, Thaxter described two species of fungi of the genus *Amphoromorpha* that were similar to organisms observed by Racovitza (1907, 1908) in terrestrial isopods. For many years, the biology of the saclike thalli described for *Amphoromorpha* was unknown, but today we know that *Amphoromorpha* thalli are secondary capilliconidia of *Basidiobolus* Eidam, 1886, a genus classified in the family Basidiobolaceae (Blackwell and Malloch 1989).

Currently, three *Amphoromorpha* species are recognized, and studies (Blackwell and Malloch 1989) suggest that *Amphoromorpha* is junior synonymy of the genus *Basidiobolus* (Mycobank 2019). Thus, we use the term *Basidiobolus* in reference to the fungus found in this study.

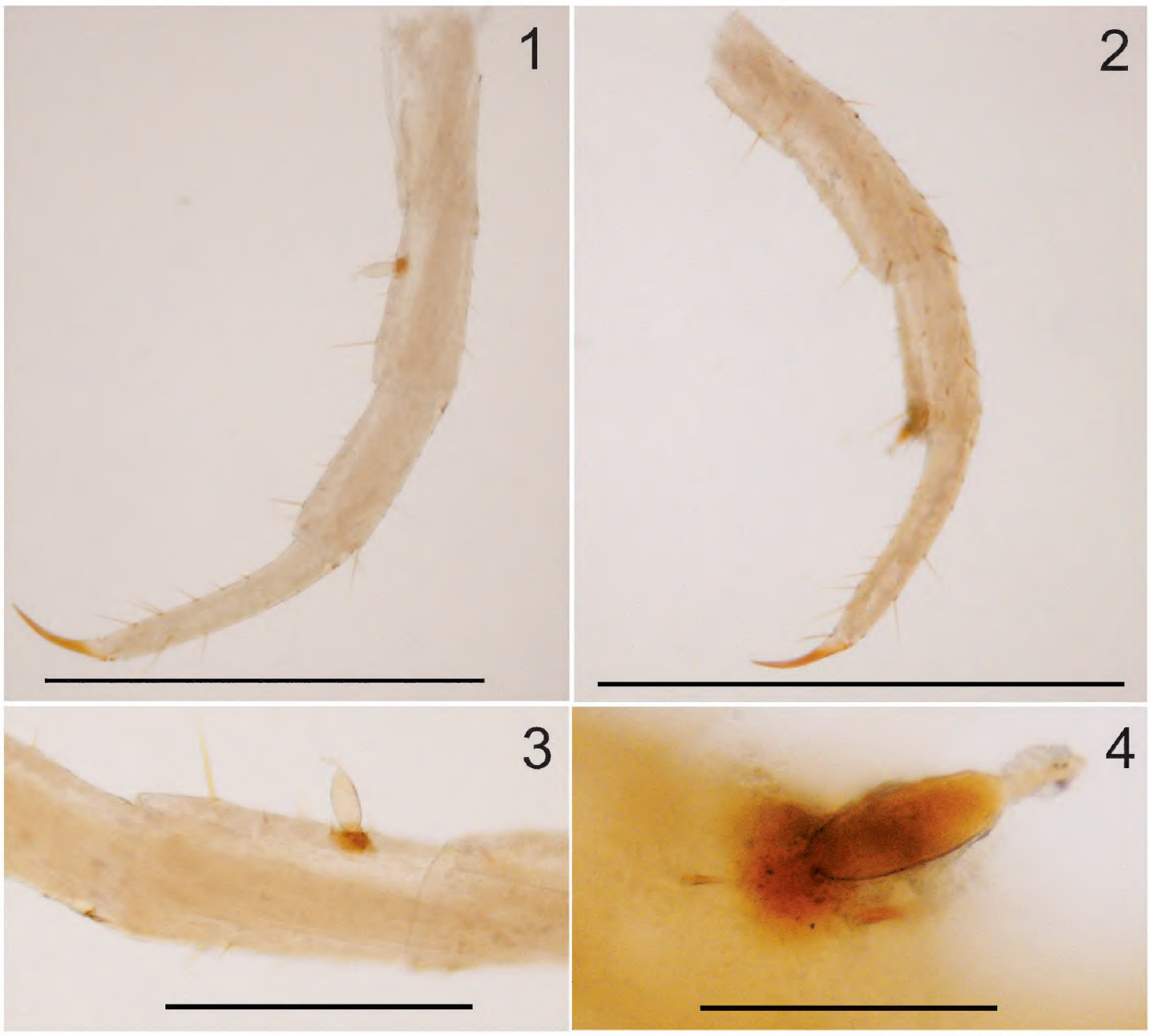
Secondary capilliconidia are asexual spores that transport through a long slender conidiophore by capillary action. During the reproductive stage, the conidiophore is evacuated from the cytoplasm, and the spore exhibits characteristics that enhance dispersal, such as an adhesive droplet at the distal end and a region of dehiscence from the conidiophore. This main feature of capilliconidia allows the spore to adhere to the surface of the arthropod exoskeleton (Blackwell and Malloch 1991, Weir and Blackwell 2005). Fungi of the genera *Amphoromorpha* and *Basidiobolus* are not classified parasites because, to our current knowledge, they do not produce haustoria, a specific structure that is used to penetrate the integument of the arthropod. Capilliconidia are phoretic spores, and they use the adhesion to arthropod integuments as a way of dispersing asexual spores.

Spore dispersion via arthropod vectors is a common propagation mechanism for many fungal species. The fungus-animal relationship is often beneficial for both partners. The arthropod transports the fungus to a new substrate, while the invertebrate is provided with a breeding ground (Basidiomycetes) or a nutrient source (Ascomycetes) (Schiestl et al. 2006). This dispersion mechanism may even be more effective than transport via wind or water as it depends on the locomotion abilities of invertebrates so that dispersion is directed to nutrient-rich environments (Lima 2012).

Our study presents the first record of a *Basidiobolus* fungus on centipedes of the order Geophilomorpha from caves in Southeast Region, Brazil.

Materials and methods

Twelve specimens of the family Geophilidae from the collection of the Coleção Zoológica do Laboratório de Estudos Subterrâneos (**LES**) of the Federal University of São Carlos (Brazil) were examined. The specimens were examined under a Leica EZ4 stereomicroscope and images were captured using a Leica M205C stereomicroscope and an Olympus BX51 photomicroscope (Wetzlar, Germany). The



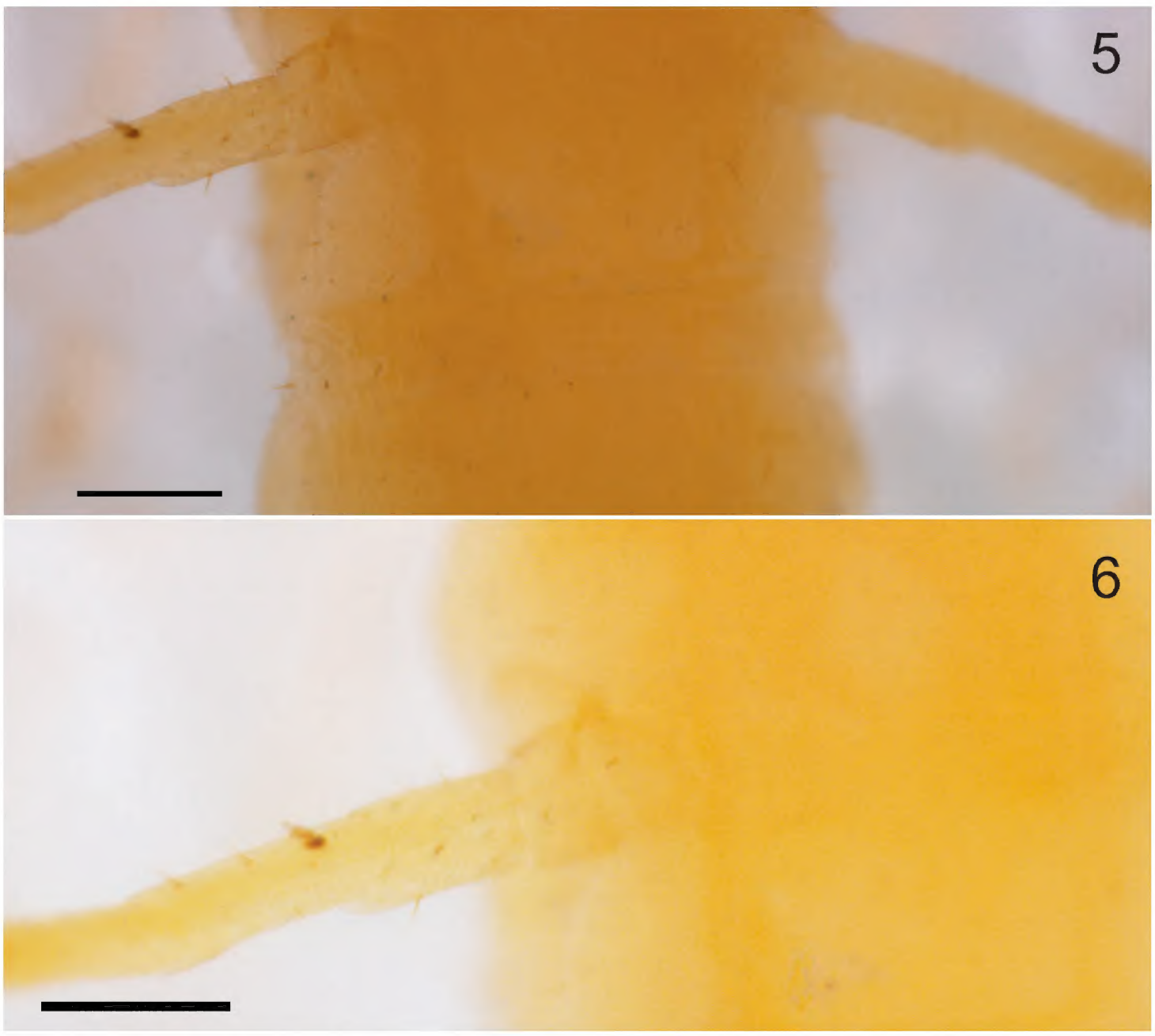
Figures 1–4. *Ribautia* sp. Brölemann, 1909 (Chilopoda: Geophilomorpha: Geophilidae) **1**. (LES 0016373) **1** Right leg 54 **2** Left leg 55 **3** Details of the fungus *Amphoromorpha/Basidiobolus* on right leg 54 **4** Details of the fungus *Amphoromorpha/Basidiobolus* on the left leg 55. Scale bars: 50.0 μm;

plates were made with the Corel DRAW X7 program (Corel Corporation, Ottawa, Canada) and length measurements were obtained in millimeters and microns using the ImageJ program.

Results

Secondary capilliconidia of *Basidiobolus* were found in the exoskeleton of two centipedes.

Two capilliconidia were observed on specimen LES 0016373, which was sampled in the Ressurgência das Areias Quentes Cave (24°33'53.0"S, 48°40'15.5"W), attached on right leg 54 and left leg 55. On right leg 54 (ventral view), the capilliconidia (14.1 μm length and 4.69 μm width) was fixed to the femur. On left leg 55 (ventral view) the capilliconidia (2.50 μm length and 0.69 μm width) was attached to the tibia (Figures 1–4).



Figures 5, 6. (LES 0010593) **5** Details of the fungus *Amphoromorpha*/*Basidiobolus* on right leg 52 **6** Details of the fungus *Amphoromorpha*/*Basidiobolus* on right leg 52. Scale bars: 200 μm.

The specimen LES 0010593, which was sampled at Areias de Cima Cave (24°35'01.7"S, 48°42'01.7"W), had one capilliconidia (38.0 μm length and 10.3 μm width) attached to right leg 52 (ventral view) (Figures 5, 6).

Discussion

Secondary capilliconidia on the surface of the arthropod exoskeleton have been observed in several groups of arthropods, such as Collembola, Blattodea, Dermaptera, Hemiptera, Heteroptera, Coleoptera, Diptera, Isopoda, Diplopoda, Pseudoscorpiones, Araneae, and Acari (Blackwell and Malloch 1989, Christian 1990, Henriksen et al. 2017).

Jiang et al. (2017) demonstrated the presence of ectoparasitic fungi of the order Entomophthorales that were parasitizing the integument of two species of *Glyphilus*, *Glyphiulus latus* Jiang, Jing-Cai, Guo, Yu & Chen, 2017 and *Glyphiulus liangshanensis*

Jiang, Jing-Cai, Guo, Yu & Chen, 2017 (Spirostreptida, Cambalopsidae). These species were collected in caves in Sichuan Province, Southeast China (Jiang et al. 2017).

With regard to Myriapoda, Enghoff and Reboleira (2017) found amphoromorphs in several millipedes, including *Boreviulisoma barrocalense* Reboleira & Enghoff, 2013, *Acipes andalusius* Enghoff & Mauriès, 1999, an unidentified species of Spirostreptidae (Spirostreptida), and an unidentified species of Paradoxosomatidae (Polydesmida) from Australia. In this same study, the authors identified a possible "*Thaxteriola*" fungus that was attached to the antenna of *Pseudonannolene spelaea* Iniesta & Ferreira, 2013 (Spirostreptida, Pseudonannolenidae) that was sampled in a cave in the state of Pará, Brazil (Iniesta and Ferreira 2013).

For centipedes, Waldock and Lewis (2014) reported the occurrence of an unidentified structure, possibly a capilliconidia, attached to the right tarsungulum of the cryptopide *Paracryptops weberi* Pocock, 1891, a species belonging to the order Scolopendromorpha.

In contrast to that observed in ectoparasite fungi on the arthropod exoskeleton (e.g., Laboulbeniales), capilliconidia of the genus *Basidiobolus* do not have a specific adhesion site on the body of the animal (Blackwell and Malloch 1989). Secondary capilliconidia randomly adheres on the surface of the exoskeleton because the only prerogative for dispersal is an arthropod or another object (including a growing hypha) that touches the spore present on another organism, organic matter, soil, or rock surface (Christian 1990).

Therefore, capilliconidia of *Basidiobolus* can be observed anywhere on the body of an arthropod. The main feature of capilliconidia in the genus *Basidiobolus* is the production of an adhesive substance that becomes very resistant to mechanical friction after being adhered to a surface (Dykstra and Bradley-Kerr 1994). The fungus uses the surface of the exoskeleton only as a support for the asexual reproductive structure and uses the host for the sole purpose of dispersing its spores (Blackwell and Malloch 1989, Weir and Blackwell 2005), the fungus does not penetrate the integument of the host and consequently is believed not to negatively affect it.

This is the first record of capilliconidia associated with centipedes of the order Geophilomorpha. Reports involving the fungus *Basidiobolus* are still scarce in the literature and few studies allow for a discussion on the relationship between the fungus and the host arthropod, especially in cave environments. The present study shows that centipede geophilomorphs are also a type of arthropod used as a host by the fungus *Basidiobolus* for the purposes of spore dispersal. Studies such as this one allow for a better understanding of the diversity of organisms that are used by the fungus *Basidiobolus* and facilitate a more integrative discussion of the ecology and life cycle of this group of fungi.

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